APPENDIX A: EMISSIONS AFTERBURNING LOADS FOR PROGRAMMATIC AND NON-PROGRAMMATIC SPACE LAUNCH ACTIVITIES

This appendix identifies the emissions/afterburning products from various propellants used in launch vehicle (LV) activities. It also discusses a methodology for determining the loads of these emissions in the various atmospheric layers and provides a table of these loads by layer. Finally, the appendix describes how the methodology can be linked with the categorization of LVs (e.g., payload capacity, launch method) proposed in the PEIS and how the programmatic and non-programmatic load of these emissions are calculated.

Emissions/Afterburning Products

The emissions/afterburning products from LV activities depend on the types of propellants used. Table A-1 provides the main emissions/afterburning products from various propellants that are currently used in spaceflight or are under development.[a,b,c,d,e,f]

TABLE A-1
MAIN EXHAUST PRODUCTS

Solid	Liquid Hydrocarbon	Hypergolic	Cryogenic	Hybrid Propellant
HCl, Al_2O_3, CO, CO_2, NO_x, Cl, H_2O	CO_2, CO, H_2, H_2O, OH	CO_2, CO, NO_x, H_2O, H_2	H_2O, H_2	CO, CO_2, H_2, H_2O, NO_x, OH

Methodology for Determining Emissions Loads in Various Atmospheric Layers

This methodology was developed to apply to categories of LVs as identified in the proposed action of the PEIS. However, to create a generalized method applicable to any LV, specific LV data (e.g., propellant type and quantity) were used and then the method was validated against emissions load data in existing EA/EIS studies of specific LV launch activities. Consequently, the specific data presented in the development of this methodology are meant to be illustrative only. Later in this appendix, the application of the methodology to the categories of LVs discussed in the proposed action will be explained.

There are four principal layers in the Earth's atmosphere: the troposphere, stratosphere, mesosphere, and ionosphere. They are generally defined by temperature, structure, density, composition and degree of ionization.[g] The approximate altitude of these layers is provided in Table A-2. The troposphere is the turbulent and weather region containing 75 percent of the total mass of the Earth's atmosphere. The troposphere is critical because any rocket emissions can potentially increase ambient pollution in the air or can fall back or be rained back to Earth. The stratosphere contains a critical ozone layer for protection from ultraviolet radiation. Both the stratosphere and the troposphere are of most concern when considering greenhouse gases and global warming.

TABLE A-2
ALTITUDE RANGE FOR VARIOUS ATMOSPHERIC LAYERS

	Troposphere	Stratosphere	Mesosphere	Ionosphere
Altitude Range	Surface to 10 km	10 to 50 km	50 to 80 km	80 to 1,000 km

LVs used to transport payloads into orbit will be propelled through several layers of the atmosphere including the troposphere, stratosphere, mesosphere, and ionosphere. The load of the emissions in each of these atmospheric layers depends on the stage firing, the type of propellant, the burn rate of propellant, and the residence time in the atmospheric layer. In developing the following methodology, the initial focus was on the tropospheric and the stratospheric layers that are generally viewed with greater concern environmentally. Also, the methodology was tested using solid rocket propellant because most programmatic LVs use solid rocket motors from launch through both the troposphere and stratosphere. It was assumed that the solid rocket propellant was hydroxy-terminated polybutadiene ammonium perchlorate and aluminum powder. HCl emissions were also a focus because of concerns for both ground exposure and ozone depletion. Using various reference sources,[h,i,j] a residence time of between 120 and 140 seconds was found to be typical for a variety of LVs to go from launch through the stratosphere (50 km). This residence time range was used as the basis for determining the emissions loads in the troposphere and stratosphere. Using the information from Table 5-2 in Section 5 of the PEIS, the quantity of solid rocket motor propellant expended during the first 120 seconds of the flight for any vehicle was first determined. Then, this quantity was multiplied by a weight fraction of HCl produced from a quantity of propellant burned. The weight fraction for HCl varied only narrowly from 17 to 21 percent in six different studies covering six different rockets as shown in Table A-3.[k,l,m,n,o,p] To be conservative, 21 percent was used.

TABLE A-3
HCl WEIGHT FRACTION EMISSIONS

HCl Weight Fraction	Endnote Reference
0.207	m
0.17	n
0.17	l
0.2	o
0.206	k
0.206	p

Table A-4 presents the calculated HCl load to the troposphere and the stratosphere for a variety of LVs. The calculated HCl load was then further validated against three EA/EIS studies that provided the quantity of HCl that could impact ozone depletion and the environment. In these studies, the HCl evaluated for ozone depletion was the quantity of HCl emissions released to both the troposphere and stratosphere. The results obtained using this methodology generally were more conservative yet still correlated with the data in the EA/EISs.

TABLE A-4

LOAD OF HCl TO TROPOSPHERE AND STRATOSPHERE COMBINED

Vehicle (payload capacity)	Solid Propellant Burned (kg) in Troposphere and Stratosphere *	Calculated HCl Load (kg) in Troposphere and Stratosphere **	HCl Load (kg) in EA/EISs
Taurus (S)	56,500	11,900	--
Taurus XL (S)	58,000	12,200	--
Pegasus (S)	10,000 + airplane	2,100	--
Delta 6925 (M)	90,000	18,900	--
Delta 7925 (I)	105,300	22,100	--
Atlas IIAS (I)	40,800	8,600	7,200 - endnote n
LMV2 (S)	70,800	14,900	--
Conestoga (S)	60,000	12,600	--
LLV2 (S)	74,500	15,600	14,300 -endnote l
LLV3 (4 strap ons) (I)	114,500	24,000	--
LLV3 (6 strap ons) (I)	134,500	28,300	--
Titan III (H)	420,000	88,200	--
Titan IV (VH)	540,000	113,000	110,000 - endnote m

* Quantities based on various documents [q]
**Calculated based on equation (Quantity of solid rocket propellant)(0.21) = Quantity of HCl

This method could be easily applied to the other emissions because weight fraction information is available. The following weight fractions for emissions in Table A-5 are based on various studies.[r,s,t,u,v] There was generally a narrow range for Al_20_3, HCl, and Cl. To be conservative, the highest percentage for Al_2O_3, HCl, and Cl were selected. In most studies, the weight fraction information for CO, CO_2, and H_2 pertains to the exhaust directly from the nozzle and not after the exhaust could react with the air. However, most studies acknowledge that in the troposphere and stratosphere, the CO will almost completely react to CO_2 in the high temperatures of the exhaust plume. Likewise, H_2 in the exhaust plume will almost completely react to form H_2O. Consequently, the CO, CO_2, H_2O in Table A-5 have been calculated based on the assumption that all of the CO goes to CO_2 and all of the H_2 goes to H_2O.

TABLE A-5

WEIGHT FRACTION OF OTHER SOLID ROCKET PROPELLANT EMISSIONS

HCl	Al_2O_3	Cl	CO_2	CO	NO_2	N_2	H_20
0.21	0.38	0.0028	0.46	-	0.0033	-	0.27

In the mesosphere, where the oxidation reaction is less likely to occur because of the lack of oxygen, the weight fractions at the exhaust nozzle are 0.23 for CO and 0.03 for CO_2.

To determine loads to the troposphere, stratosphere, and mesosphere individually, individual residence times for the rockets were needed. From a few select EA/EISs,[w,x] it was determined that generally the residence time in the troposphere, stratosphere and mesosphere was approximately 60 seconds, 60 seconds, and 50 seconds, respectively. The approach to determine the residence time for the stratosphere was validated by comparing the calculation of the chlorine emissions to the stratosphere from rocket exhaust with a report by Prather (1990) that asserted that the Titan IV launcher contributed 32 tons of Cl to the stratosphere.[y] Using the assumptions that the stratosphere begins above 15 kilometers, the Cl input from the Titan IV was calculated as 37 tons. The above residence times probably do not predict the behavior of the Pegasus Rocket that is usually launched at the troposphere/stratosphere boundary at essentially zero upward velocity.

Using Above Methodology with LV Categories in Proposed Action

Payload capacity (an LV Category) is closely related to the quantity of propellant used, although other factors play a role. Almost all programmatic LVs use only solid propellant to propel the rocket through the troposphere and stratosphere. Consequently, the quantity of solid propellant used in the first 120 seconds of flight may be related to the payload capacity sizes (small, medium, intermediate, high). From Table A-4, the appropriate payload capacity size was assigned to each vehicle (see letter designation in vehicle column). Aside from the Altas rocket that also uses liquid and solid propellant at liftoff, there seems to be a possible relationship between payload capacity size and solid propellant quantity (Table A-6). To be conservative in assembling Table A-6, the largest quantity for a rocket in each payload capacity was selected. To determine programmatic load from this relationship, the number of the 436 projected programmatic LV launches (from the proposed action) that would be powered by solid propellant and their payload capacities would need to be determined. The total load of all solid rocket emissions to the troposphere and stratosphere could then be calculated.

TABLE A-6

RELATIONSHIP BETWEEN PAYLOAD CAPACITY AND SOLID PROPELLANT QUANTITY

Payload Capacity	Quantity (kg) of Solid Propellant into Troposphere and Stratosphere Combined	Quantity (kg) of Solid Propellant into Troposphere flight time 0-60 seconds	Quantity (kg) of Solid Propellant into Stratosphere flight time 60-120 seconds
small	75,000	37,500	37,500
medium	90,000	45,000	45,000
intermediate	135,000	67,500	67,500
high	420,000	210,000	210,000

Application of Method to Liquid, Liquid/Solid, and Hybrid Propellant Rockets

Some LVs use other propellants at launch or may use two different types of propellants simultaneously (i.e., Atlas IIAS solid/liquid) during a single stage. The emissions would be some combination of the propellant emissions. The approach can be used with liquid (hydrocarbon/hydrazine) and hybrid rockets. The residence time, burn rate of the propellant, and if the propellant was ignited at launch or after the rocket exits the stratosphere would be used. The weighted emission values for the liquids hydrocarbon (LOX-RP1) and liquid hydrazine are presented below in Tables A-7 and A-8. Because hybrid propellant rockets are under development, literature references detailing the emission weighted fractions of emissions from these LV propulsion systems are not available. If none is available, the reaction product quantities could be estimated based on a reaction kinetics of LOX and solid propellant (i.e., hydroxy-terminated polybutadiene). It was assumed that the emission weighted fractions are similar to the weighted fractions for the LOX/RP1 rocket propellants. Weighted fraction emissions are provided in Table A-9 for LVs that use both liquid hydrocarbon and solid propellant at liftoff.

TABLE A-7

WEIGHT FRACTION OF LIQUID HYDROCARBON (LOX-RP1) EMISSIONS

CO_2	CO	OH	H_2	H_2O
0.931	--	0.035	0.0099	0.25

In the mesosphere, where the oxidation reaction is less likely to occur because of the lack of oxygen, the weight fractions at the exhaust nozzle are 0.44 for CO and 0.24 for CO_2.

TABLE A-8

WEIGHT FRACTION OF LIQUID HYPERGOLS (N_2O_4-AEROZINE 50) EMISSIONS

CO_2	CO	NO_2	N_2	H_20
0.22	--	1.36	--	0.35

In the mesosphere, where the oxidation reaction is less likely to occur because of the lack of oxygen, the weight fractions at the exhaust nozzle are 0.03 for CO and 0.18 for CO_2.

TABLE A-9

WEIGHT FRACTION OF LIQUID HYDROCARBON (LOX-RP1)/SOLID PROPELLANT EMISSIONS (DUAL USE; ATLAS)*

HCl	Al_2O_3	Cl	CO_2	CO	NO_2	N_2	H_20	OH	H_2
0.105	0.185	0.0014	0.1	-	0.68	-	0.31	0.017	0.005

*Assumes 50% liquid hydrocarbon and 50% Solid propellant.

In the mesosphere, where the oxidation reaction is less likely to occur because of the lack of oxygen, the weight fractions at the exhaust nozzle are 0.34 for CO and 0.13 for CO_2.

Calculation of Emission Loads for Programmatic Activities

Programmatic activities include anticipated U.S. licensed LV launches. Table A-10 provides information and estimates used to make calculations of emissions load to the troposphere and stratosphere. Table A-10 estimates the number of programmatic launches in the U.S. from 1998-2009 by payload capacity. The estimates are based on several commercial market projections including the Commercial Spacecraft Mission Model Update (May 1998)[z] and the 1998 LEO Commercial Market Projection (May 1998)[aa]. The number of launches in the small capacity payload also includes 24 U.S commercial sounding rockets and NASA/DOD FAA-licensed rockets.[bb] The table also estimates the percent expenditure of different propellants used in the troposphere/stratosphere based on the types of rocket in each payload capacity. The number of launches in each payload capacity is then multiplied by the percentages to give the number of LVs using certain propellant types within each payload capacity. The same information is provided for the mesosphere.

TABLE A-10

ESTIMATED NUMBER OF COMMERCIAL PROGRAMMATIC U.S. LAUNCHES 1998-2009 BY PAYLOAD AND PROPELLANT TYPE

Payload Capacity	Estimated Launches	Percent Rockets using Various Propellant Types Used During Flight through Troposphere/ Stratosphere	Number of Flights Using Propellant Type in Troposphere/ Stratosphere	Propellant Types Used During Flight through Mesosphere	Number of Flights Using Propellant Type in Mesosphere
Small	173	100% Solid	173	100% Solid	173
Medium	73	100% Solid	73	50% Solid 25% Solid/LOX-RP1 25% Solid/Hypergol	37 18 18
Intermediate	102	25% Solid 25% Solid/LOX-RP1 25% LOX-RP1 25% Hybrid	26 26 25 25	20% Solid 30% LOX-RP1 25% Hypergol 25% Hybrid	21 31 25 25
High	88	33% Solid 33% Solid/LOX-RP1 33% Hybrid	30 29 29	33% LOX-RP1 33% Hypergol 33% Hybrid	30 29 29

Table A-11 presents the load to the troposphere from programmatic U.S. launches from 1998-2009. The table uses information from many of the above tables. The load to the stratosphere will be the same as the load to the troposphere because the residence time is the same (60 seconds) and the propellant type used is the same. However the load to the mesosphere will have to be calculated using a 50 second residence time and the types of propellant listed in Table A-10. Table A-12 provides the loads to the mesosphere. The propellant quantities associated with the flight in the mesosphere were based on quantities used in current programmatic LV activities and based on an AIAA document.[cc]

TABLE A-11

ESTIMATED EMISSION LOADS TO TROPOSPHERE FROM PROGRAMMATIC U.S. COMMERCIAL LAUNCHES FROM 1998-2009

Payload Capacity	Percent Rockets using Various Propellant Types Used During Flight through Troposphere/ Stratosphere	Number of Flights Using Propellant Type in Troposphere	Propellant Quantity Associated with Flight in Troposphere (flight time 0-60 seconds)	HCl Load (kg x 10^3)	CO_2 Load (kg x 10^3)	H_2O Load (kg x 10^3)	N_2 Load (kg x 10^3)	Cl Load (kg x 10^3)	Al_2O_3 Load (kg x 10^3)
Small	100% Solid	173	37,500	1,362	2,984	1,752	545	18	2,465
Medium	100% Solid	73	45,000	690	1,511	887	276	9	1,248
Intermediate	25% Solid	26	67,500	369	807	474	147	5	667
	25% Solid/LOX-RP1	26	67,500	184	1,229	456	72	2	325
	25% LOX-RP1	25	67,500	-	1,569	422	-	-	-
	25% Hybrid	25	67,500	-	1,569	422	-	-	-
High	33% Solid	30	210,000	1,323	2,898	1,701	529	18	2,394
	33% Solid/LOX-RP1	29	210,000	639	4,263	1,583	250	9	1,127
	33% Hybrid	29	210,000	-	5,663	1,523	-	-	-
Total (kg x 10^3)				4,568	22,495	9,219	1,819	61	8,226
Total (tons)*				5,024	24,744	10,141	2,001	67	9,048

*Ton equals 2,000 lbs

TABLE A-12

ESTIMATED EMISSION LOADS TO MESOSPHERE FROM PROGRAMMATIC U.S. COMMERCIAL LAUNCHES FROM 1998-2009

Payload Capacity	Percent of Rockets using Various Propellant Types Used During Flight through Mesosphere	Number of Flights Using Propellant Type in Mesosphere	Propellant Quantity Associated with Flight in Mesosphere (flight time 120-170 seconds)	HCl Load (kg x 10^3)	$Al_2 0_3$ Load (kg x 10^3)	CO_2 Load (kg x 10^3)	CO Load (kg x 10^3)	H_2O Load (kg x 10^3)	N_2 Load (kg x 10^3)	Cl Load (kg x 10^3)	NO_x Load (kg x 10^3)
Small	100% Solid	173	5,000	182	320	26	199	234	73	2	-
Medium	50% Solid	37	17,500	136	240	19	149	175	54	2	-
	25% Solid/LOX-RP1	18	17,500	33	58	41	107	82	13	0.4	-
	25% Solid/Hypergol	18	17,500	33	58	32	41	98	66	0.4	6
Intermediate	20% Solid	21	30,000	132	2,331	19	145	170	53	2	-
	30% LOX-RP1	31	25,000	-	-	186	341	194	-	-	-
	25% Hypergol	25	25,000	-	-	113	19	219	256	-	12
	25% Hybrid	25	25,000	-	-	150	275	156	-	-	-
High	33% LOX-RP1	30	55,000	-	-	396	726	413	-	-	-
	33% Hypergol	29	55,000	-	-	287	48	558	654	-	31
	33% Hybrid	29	55,000	-	-	383	702	399	-	-	-
Total (kg x 10^3)				516	909	1,651	2,751	2,696	1,169	7	48
Total (tons)*				568	1,000	1,816	3,026	2,966	1,286	8	53

*Ton equals 2000 lbs

Calculation of Emission Loads for Non-Programmatic Activities

Non-programmatic activities include anticipated U.S. Government space activities (non-licensed e.g., NASA, USAF), foreign government (e.g., Russia, Europe, China, Japan, etc.) space activities, international (e.g., Ariane) commercial activities and civil aviation industry, and all other industrial activities. Table A-13 estimates the number of non-programmatic launches from 1998-2009 by payload capacity. The basis for the estimates are provided in the table.

TABLE A-13

ESTIMATED NUMBER OF NON-PROGRAMMATIC LAUNCHES 1998-2009 BY PAYLOAD AND PROPELLANT TYPE*

Non-Programmatic Subcategory	Estimated Launches from 1998-2009	Payload Capacity	Number of Flights
U.S. Government	342	Small	69
		Medium	151
		Intermediate	13
		High/Very High	109
Foreign Government	750	Small	44
		Medium	128
		Intermediate	313
		High/Very High	265
International Commercial	275	Small	16
		Medium	47
		Intermediate	115
		High/Very High	97

*U.S. launches based on total estimates from NASA's Expendable Launch Vehicle and Upper Stages Manifest[dd], DOD launch rates for the Evolved Expendable Launch Vehicle Program[ee], and 8 Space Shuttle Flights per year. Foreign Government launches include launches from Russia, ESA, China, and Japan. The estimates are based on a study by Teal Group Corp. (for Russia, China, and ESA), data from ESA, 1994, and extrapolations from launch history (Japan).[ff] For international commercial launches, the number of flights were the world-wide estimate of commercial launches minus the U.S. government commercial launches. Note that before making this calculation in the small payload capacity category, 48 sounding and DOD/NASA FAA-licensed launches were excluded from the U.S. totals. In terms of the distribution of the foreign government launches in the various payload capacity categories, it was assumed that the profile of rockets for the foreign government was the same as the international commercial launches.

Table A-14 presents the load to the troposphere from non-programmatic U.S. Government launches from 1998-2009. The table uses information from many of the above tables. For the small payloads, the propellant quantities and propellant types were based on estimates used in the programmatic U.S. commercial launches. For the high/very high payloads, the propellant quantities and propellant types were based on the Titan IV and the Shuttle rather than the high payload rockets expected to be used commercially.[gg] Note that the load to the troposphere will be the same as the load to the stratosphere because the residence time is the same (60 seconds) and the propellant type use is the same. However, the load to the mesosphere is presented in Table 15 and is calculated using a 50 second residence time. The choice of propellant quantities and propellant types used in Table 15 are based on the same reasoning and data sources used in the above analysis of load to the troposphere from U.S. Government launches.[hh]

TABLE A-14

ESTIMATED EMISSION LOADS TO TROPOSPHERE FROM NON-PROGRAMMATIC U.S. GOVERNMENT LAUNCHES FROM 1998-2009

Payload Capacity	Percent of Rockets using Various Propellant Types Used During Flight through Troposphere/ Stratosphere	Number of Flights Using Propellant Type in Troposphere	Propellant Quantity Associated with Flight in Troposphere (flight time 0-60 seconds)	HCl Load (kg x 10^3)	CO_2 Load (kg x 10^3)	H_2O Load (kg x 10^3)	N_2 Load (kg x 10^3)	NOx Load (kg x 10^3)	Cl Load (kg x 10^3)	Al_2O_3 Load (kg x 10^3)
Small	100% Solid	69	37,500	543	1,190	699	217	-	7	983
Medium	33% Solid	51	45,000	482	1,056	620	193	-	6	872
	33%/Solid LOX-RP1	50	45,000	236	1,575	585	92	-	3	416
	33% LOX-RP1	50	45,000	-	2,093	563	-	-	-	-
Intermediate	33% Solid	5	67,500	71	155	91	28	-	0.9	128
	33%/Solid LOX-RP1	4	67,500	28	189	70	11	-	0.3	50
	33% LOX-RP1	4	67,500	-	251	68	-	-	-	-
High/Very High	5% Solid	6	242,000	305	668	392	122	-	4	552
	90% LOX-H2/Solid	98	586,000**	10,251	22,454	21,823	4,100	-	137	18,549
	5% LOX-RP1	5	500,000***	-	2,325	625	-	-	-	-
Total (kg x 10^3)				11,917	31,956	25,534	4,764	-	159	21,551
Total (tons)*				13,108	35,152	28,088	5,241	-	175	23,706

*Ton equals 2,000 lbs

**Based on Space Shuttle assuming 502,000 kg solid and 84,000 kg LOX-H2 (one minute burn in troposphere of total 8 minute 40 second burn time of 721,000 kg).

***Based on new Evolved Expendable Launch Vehicle Concept

TABLE A-15

ESTIMATED EMISSIONS LOAD TO MESOSPHERE FROM NON-PROGRAMMATIC U.S. GOVERNMENT LAUNCHES FROM 1998-2009

Payload Capacity	Percent of Rockets using Various Propellant Types Used During Flight through Mesosphere	Number of Flights Using Propellant Type in Mesosphere	Propellant Quantity Associated with Flight in Mesosphere (flight time 120-170 seconds)	HCl Load (kg x 10^3)	$Al_2 0_3$ Load (kg x 10^3)	CO_2 Load (kg x 10^3)	CO Load (kg x 10^3)	H_2O Load (kg x 10^3)	N_2 Load (kg x 10^3)	Cl Load (kg x 10^3)	NO_x Load (kg x 10^3)
Small	100% Solid	69	5,000	72	128	10	79	93	29	1	-
Medium	33% Solid	51	15,000	161	283	23	176	207	64	2	-
	33% LoX-RP1	50	15,000	-	-	180	330	188	0	-	-
	33% Hypergol	50	15,000	-	-	135	23	263	308	-	14
Intermediate	33% Solid	5	30,000	32	56	5	35	41	13	0.4	-
	33% LOX-RP1	4	25,000	-	-	24	44	25	0	-	-
	33% Hypergol	4	25,000	-	-	18	3	35	41	-	2
High	10% Hypergol	11	43,000	-	-	85	14	166	194	-	9
	90% LOX-H_2	98	70,000**	-	-	-	-	6,860	-	-	-
Total (kg x 10^3)				265	466	480	703	7,876	648	4	25
Total (tons)*				291	513	528	774	8,663	713	4	28

*Ton equals 2000 lbs

**Based on Space Shuttle and EEVL assuming 50 second burn in mesosphere of total 8 minute 40 second burn time of 721,000 kg

To estimate the load from commercial international (non-U.S.) and foreign governments, specific international rocket vehicles that are being used or are being developed were examined. These included the following vehicles Zenit (Russia), Proton (Russia), Ariane IV and V (ESA), Long March (China), H2 (Japan), GSLV (India), PSLV (India), and M-V (Japan). The propellant quantities and propellant types were determined from several sources [ii] as well as which propellant types would be used in the various layers of the Earth's atmosphere. The data and basis for the number of international commercial (non-U.S.) flights was provided in Table A-13. An estimated 275 international commercial launches are expected from 1998-2009. The loads to the troposphere from international commercial launches is provided in Table A-16. The load to the stratosphere is the same as the load to the troposphere because the residence time and the propellant types used in both atmospheric layers is basically the same. The load to the mesosphere is provided in Table A-17.

In terms of the loads from the foreign governments, it was assumed that the profile of rockets for the foreign government launches was the same for the international commercial launches. The only difference was the number of international launches (275 launches) versus foreign government launches (750 launches) (see table 13 for basis). Consequently, the loads from commercial international were simply multiplied by the factor 3 to represent the increase in the number of foreign government launches. The load from foreign government launches to the troposphere, stratosphere, and mesosphere is provided in the Table A-18.

TABLE A-16

ESTIMATED EMISSION LOADS TO TROPOSPHERE FROM NON-PROGRAMMATIC INTERNATIONAL COMMERCIAL LAUNCHES FROM 1998-2009

Payload Capacity	Percent of Rockets using Various Propellant Types Used During Flight through Troposphere/ Stratosphere	Number of Flights Using Propellant Type in Troposphere	Propellant Quantity Associated with Flight in Troposphere (flight time 0-60 seconds)	HCl Load (kg x 10^3)	CO_2 Load (kg x 10^3)	H_2O Load (kg x 10^3)	N_2 Load (kg x 10^3)	Cl Load (kg x 10^3)	Al_2O_3 Load (kg x 10^3)	NO_x Load (kg x 10^3)
Small	100% Solid	16	50,000	168	368	216	67	2	304	-
Medium	100% Solid	47	65,000	642	1,405	825	257	9	1,161	-
Intermediate	60% Solid	69	80,000	1,159	2,539	1,490	464	15	2,098	-
	40% Hybrid	46	80,000	-	3,422	920	-	-	-	-
High	10% Solid/LOX-H_2	10	90,000	161	352	342	64	2	2,907	-
	40% Hypergol	39	140,000	-	1,201	1,911	-	-	-	7,426
	20% LOX-RP1	19	130,000	-	2,297	618	-	-	-	-
	20% Hybrid	19	130,000	-	2,297	618	-	-	-	-
	10% Solid/Hypergol	10	140,000	147	140	434	-	2	259	952
Total (kg x 10^3)				2,276	14,022	7,373	852	30	4,112	8,378
Total (tons)*				2,504	15,424	8,110	937	33	4,523	9,215

*Ton equals 2,000 lbs

TABLE A-17

LOAD TO MESOSPHERE FROM NON-PROGRAMMATIC INTERNATIONAL COMMERCIAL LAUNCHES FROM 1998-2009

Payload Capacity	Percent of Rockets using Various Propellant Types Used During Flight through Mesosphere	Number of Flights Using Propellant Type in Mesosphere	Propellant Quantity Associated with Flight in Mesosphere (flight time 120-170 seconds)	HCl Load (kg x 10^3)	Al_2O_3 Load (kg x 10^3)	CO_2 Load (kg x 10^3)	CO Load (kg x 10^3)	H_2O Load (kg x 10^3)	N_2 Load (kg x 10^3)	Cl Load (kg x 10^3)	NO_x Load (kg x 10^3)
Small	100% Solid	16	5,000	17	30	2	18	22	7	0.22	-
Medium	50% Solid	23	10,000	48	85	7	53	62	19	0.64	-
	25% Hypergol	12	10,000	-	-	22	4	42	49	-	2
	25% LOX-RP1	12	10,000	-	-	29	53	30	-	-	-
Intermediate	55% Hypergol	63	12,000	-	-	136	23	265	310	-	14
	45% Hybrid	52	12,000	-	-	150	275	156	-	-	-
High/Very High	60% Hypergol	58	82,000	-	-	856	143	1,665	1,950	-	90
	20% LOX-RP1	20	90,000	-	-	432	792	450	-	-	-
	20% Hybrid	19	90,000	-	-	410	752	428	-	-	-
Total (kg x 10^3)				65	115	2,044	2,112	3,188	2,335	0.87	107
Total (tons)*				72	126	2,248	2,323	3,430	2,569	0.96	118

*Ton equals 2000 lbs

TABLE A-18

ESTIMATED EMISSIONS LOAD TO TROPOSPHERE, STRATOSPHERE, AND MESOSPHERE FROM NON-PROGRAMMATIC FOREIGN GOVERNMENT LV LAUNCHES FROM 1998-2009

Atmospheric Layer	HCl Load (tons)	CO_2 Load (tons)	CO Load (tons)	H_2O Load (tons)	N_2 Load (tons)	Cl Load (tons)	Al_2O_3 Load (tons)	NOx Load (tons)
Troposphere	6802	42297	-	22101	2553	91	12288	24923
Stratosphere	6802	42297	-	22101	2553	91	12288	24923
Mesosphere	199	6132	6318	9370	7035	2.6	350	322

Ton equals 2,000 lbs

Summary Comparison of Programmatic and Non-Programmatic Loads

A summary of emission loads from programmatic and non-programmatic launch activities is provided in Table A-19. Note that all of the programmatic emission loads for both the troposphere and stratosphere are approximately 22% of the non-programmatic loads. In the mesosphere, the programmatic load for HCl, Al_20_3, and Cl is approximately the same as the programmatic load. For CO/CO_2, the programmatic load is approximately 20-30% of the non-programmatic load and for NO_x, the programmatic load is 9% of the non-programmatic load.

TABLE A-19

SUMMARY OF PROGRAMMATIC AND NON-PROGRAMMATIC EMISSION LOADS TO EARTH'S ATMOSPHERE FROM LAUNCHES FROM 1998-2009

Atmospheric Layer	Programmatic Non-Programmatic	HCl Load (tons)	CO_2 Load (tons)	CO Load (tons)	H_2O Load (tons)	N_2 Load (tons)	Cl Load (tons)	Al_2O_3 Load (tons)	NO_x Load (tons)
Troposphere	Programmatic	5,024	24,744	-	10,141	2,001	67	9,048	-
	Non-Programmatic	22,414	92,873	-	58,299	8,730	299	40,518	34,139
Stratosphere	Programmatic	5,024	24,744	-	10,141	2,001	67	9,048	-
	Non-Programmatic	22,414	92,873	-	58,299	8,730	299	40,518	34,139
Mesosphere	Programmatic	568	1,816	3,026	2,966	1,286	7.6	1,000	53
	Non-Programmatic	561	8,908	9,414	21,463	10,316	7.5	989	468

Ton equals 2,000 lbs

[a] Department of the Air Force. Draft Programmatic Environmental Assessment Medium Launch Vehicle III Program. June 1991.

[b] Department of the Air Force. Environmental Assessment Lockheed Launch Vehicles, Vandenberg Air Force Base, CA. April 1994.

[c] Department of the Air Force. Environmental Assessment Titan IV/Solid Rocket Motor Upgrade Program, Cape Canaveral Air Force Station, FL, Vandenberg Air Force Base, CA. February 1990.

[d] Versar, Inc. Final Environmental Assessment Vandenberg Air Force Base Atlas II Program. August 1991.

[e] NSWC Indian Head Division. Combustion Products of Solid Rocket Motors. August 1996.

[f] Environmental Assessment for Complementary Expendable Launch Vehicle. June 1986.

[g] Department of Transportation. Environmental Impact Statement for Commercial Reentry Vehicles. Washington, May 1992.

[h] Department of the Air Force. Environmental Assessment Lockheed Launch Vehicles, Vandenberg Air Force Base, CA. April 1994.

[i] Department of the Air Force. Environmental Assessment Titan IV/Solid Rocket Motor Upgrade Program, Cape Canaveral Air Force Station, FL, Vandenberg Air Force Base, CA. February 1990.

[j] Versar, Inc. Final Environmental Assessment Vandenberg Air Force Base Atlas II Program. August 1991.

[k] Department of the Air Force. Draft Programmatic Environmental Assessment Medium Launch Vehicle III Program. June 1991.

[l] Department of the Air Force. Environmental Assessment Lockheed Launch Vehicles, Vandenberg Air Force Base, CA. April 1994.

[m] Department of the Air Force. Environmental Assessment Titan IV/Solid Rocket Motor Upgrade Program, Cape Canaveral Air Force Station, FL, Vandenberg Air Force Base, CA. February 1990.

[n] Versar, Inc. Final Environmental Assessment Vandenberg Air Force Base Atlas II Program. August 1991.

[o] NSWC Indian Head Division. Combustion Products of Solid Rocket Motors. August 1996.

[p] Environmental Assessment for Complementary Expendable Launch Vehicle. June 1986.

[q] Isakowitz, Steven J. International Reference Guide to Space Launch Systems. 2nd ed. Washington: American Institute of Aeronautics and Astronautics, 1995.

[r] Department of the Air Force. Draft Programmatic Environmental Assessment Medium Launch Vehicle III Program. June 1991.

[s] Department of the Air Force. Environmental Assessment Lockheed Launch Vehicles, Vandenberg Air Force Base, CA. April 1994.

[t] Department of the Air Force. Environmental Assessment Titan IV/Solid Rocket Motor Upgrade Program, Cape Canaveral Air Force Station, FL, Vandenberg Air Force Base, CA. February 1990.

[u] Versar, Inc. Final Environmental Assessment Vandenberg Air Force Base Atlas II Program. August 1991.

[v] NSWC Indian Head Division. Combustion Products of Solid Rocket Motors. August 1996.

[w] Department of the Air Force. Environmental Assessment Lockheed Launch Vehicles, Vandenberg Air Force Base, CA. April 1994.

[x] Department of the Air Force. Environmental Assessment Titan IV/Solid Rocket Motor Upgrade Program, Cape Canaveral Air Force Station, FL, Vandenberg Air Force Base, CA. February 1990.

[y] Versar, Inc. Final Environmental Assessment Vandenberg Air Force Base Atlas II Program. August 1991.

[z] Commercial Spacecraft Mission Model Update, Commercial Space Transportation Advisory Committee (COMSTAC), FAA, US.DOT, May 1998.

[aa] 1998 LEO Commercial Market Projections, Associate Administrator for Commercial Space Transportation, May 1988.

[bb] Associate Administrator for Commercial Space Transportation

[cc] Isakowitz, Steven J. International Reference Guide to Space Launch Systems. 2nd ed. Washington: American Institute of Aeronautics and Astronautics, 1995.

[dd] Associate Administrator for Commercial Space Transportation

[ee] Final Environmental Impact Statement for Evolved Expendable Launch Vehicle Program, April 1998.

[ff] Isakowitz, Steven J. International Reference Guide to Space Launch Systems. 2nd ed. Washington: American Institute of Aeronautics and Astronautics, 1995.

[gg] Isakowitz, Steven J. International Reference Guide to Space Launch Systems. 2nd ed. Washington: American Institute of Aeronautics and Astronautics, 1995.

[hh] Isakowitz, Steven J. International Reference Guide to Space Launch Systems. 2nd ed. Washington: American Institute of Aeronautics and Astronautics, 1995.

[ii] Isakowitz, Steven J. International Reference Guide to Space Launch Systems. 2nd ed. Washington: American Institute of Aeronautics and Astronautics, 1995.